LEVEL II

2

AD A099405

HEADQUARTERS STRATEGIC AIR COMMAND

Directorate of Aircraft Maintenance

Aircraft Engineering Division

Engineering Report No. S-112

NUCLEAR HARDNESS AND BASE ESCAPE

31 March 1981

Prepared By: RAYFORD P. PATRICK, Lt Col, USAF
Staff Engineer, Survivability
and Vulnerability

APPROVED: JAMES K. STREETT, Colonel, USAF
Chief, Aircraft Engineering Division

ABSTRACT

In the event of a surprise nuclear attack, the survivability of the manned bombers depends upon their base escape capability, i.e. the ability of their alert crews, upon short notification, to react, start engines, taxi, take-off, and reach safety prior to the detonation of the first nuclear weapon on or near their base. Significant factors of successful base escape are discussed. It is argued that nuclear hardness and rapid engine start capabilities are essential and that they should be incorporated early in full scale development. It is also argued that altitude dependence can be minimized or eliminated in the nuclear blast hardness criteria if the dynamic pressure is selected as the criterion.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Engineering Report S-112 ✓	2. GOVT ACCESSION NO. AD A099405	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 NUCLEAR HARDNESS AND BASE ESCAPE.		5. TYPE OF REPORT & PERIOD COVERED 9 Final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Rayford P. Patrick		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Headquarters, Strategic Air Command Directorate of Aircraft Maintenance Aircraft Engineering Division		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 11898
11. CONTROLLING OFFICE NAME AND ADDRESS HQ SAC/LGME Offutt Air Force Base, Neb. 68113	11	12. REPORT DATE 31 March 1981
		13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 22		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

14 SAC/LGME-ER-S-112

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Nuclear Blast, Nuclear Weapons Effects, Nuclear Hardness, Nuclear Survivability/Vulnerability, Aircraft, Base Escape

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In the event of a surprise nuclear attack, the survivability of the manned bombers depends upon their base escape capability, i.e. the ability of their alert crews, upon short notification, to react, start engines, taxi, takeoff, and reach safety prior to the detonation of the first nuclear weapon on or near their base. Significant factors of successful base escape are discussed. It is argued that nuclear hardness and rapid engine start capabilities are essential and that they should be incorporated early in full scale development. It also argued that altitude dependence can be minimized or eliminated if the dynamic pressure is selected as the nuclear blast hardness criterion.

DW

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

410063

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

NUCLEAR HARDNESS AND BASE ESCAPE

INTRODUCTION

Historically the TRIAD has formed the basis for strategic deterrence for the United States. The legs of the stable TRIAD consist of land-based intercontinental ballistic missiles (ICBMs), submarine launched ballistic missiles (SLBMs), and the manned bomber. Even with improvements to the ballistic missile, the penetrating manned strategic bomber remains a critical element of our future ability to deter enemy aggression and to enhance our conventional war capability. In the event that potential enemy nations develop space-based high energy laser or particle beam weapons during the next decade they could neutralize some, or all, ballistic missiles, and the strategic manned bomber with low-level penetration capability would achieve even greater significance.

Any potential enemy realizing the significance of the bomber fleet would probably attempt to neutralize the bombers prior to their launch. There are major advantages to this strategy. First, if the bombers can be neutralized on their home bases, the enemy's homeland defense would be greatly simplified. He could concentrate only on those few surviving aircraft. Second, he could use high-yield weapons on bomber bases without concern for collateral effects. Defensive strategy against bombers penetrating his homeland at low altitudes must consider the potential effects of his own nuclear detonations on his population, facilities, and other national assets. These considerations must balance the more effective (but risky) nuclear-tipped defensive missiles with less-effective (but safer) conventional missiles. Such decisions are not enviable, even for the leaders of autocratic nations.

Since the enemy would probably consider bomber bases as high-priority targets, it behooves us to counter via measures to increase the probability of base escape, P_{BE}, of our bomber fleet. This study addresses the major factors involved in base escape analyses, and argues the strong urgency in the incorporation of conservative nuclear hardness levels and engine start times <u>early</u> in the acquisition program of new strategic aircraft.

BASE ESCAPE

The probability of base escape is a function primarily of crew reaction time, aircraft reaction time, taxi time, fly out time, basing, and nuclear hardness. The crew reaction time is defined here as the time between klaxon and crew arrival at the aircraft. Aircraft reaction time is the time from crew arrival at the aircraft to start of taxi. Taxi time is the time from start of taxi to start of take-off roll. Fly out time is the time from start of take-off roll to the safe-escape point. (The safe-escape point is defined by aircraft hardness to blast and thermal environments generated by the enemy detonation(s), and the type of attack on the base i.e. "one over the runway" versus pattern attack.) Basing refers simply to the manner in which the alert bombers are deployed, i.e. all stand alert on home base versus the other extreme of dispersing all alert bombers to other air fields. Nuclear hardness is the capability of the bomber to withstand exposure to various environments generated by nuclear weapon detonations <u>without</u> loss of mission completion capability.

Aircrew reaction time can range from several minutes if the crews are restricted to the base, to a minute or so if they are restricted to the alert facility, to essentially zero if they are on cockpit alert.

Aircraft reaction times are usually dominated by engine start times. Alert aircraft are "cocked", i.e. many of the checklist items have been completed, and the cockpits are configured for engine start. Engine start is dependent upon adequate supplies of high pressure air/gas to motor the jet engines to starting RPM, and electrical power to fire the ignitors. The high-pressure air/gas may be supplied by on-board auxiliary power units (APUs), by ground support equipment, by starter cartridges or other auxiliary device, and/or by an operating engine. One technique (in use on B-52 and KC-135 aircraft prior to the Quick Start modification) is to start one (or two) engine(s) using a starter cartridge, on-board APU, or ground unit. After one engine is operating it can supply enough air to simultaneously start the remaining engines. Another technique is the simultaneous starting of all engines which requires starter cartridges for each engine (the essence of the Quick Start modification was the incorporation of cartridge start capability on each engine on the B-52G/H and KC-135A), or the use of APUs/start carts with the output volume of high pressure air sufficient to motor <u>all</u> engines simultaneously to starting RPM within some maximum time (30-60 seconds, generally).

The reaction time required for engine start for the first technique above is about twice the time for the second. However there are extra costs, both nonrecurring and recurring, for the added capability. For example, the Quick Start modification included the development, added hardware, technical data change, and modification manhour costs (nonrecurring). In addition, the logistic support costs increased as did the cost of expending more cartridges per alert start (recurring). Another example may be the necessity for larger, or multiple APUs and/or ground units to provide the larger volume of high pressure air required for simultaneous engine start. Again, both recurring and nonrecurring costs would increase.

Electrical power for ignition and communication with the command post can be supplied either by aircraft batteries or by ground power units. Generally aircraft battery starts are preferable (if reliable) with ground units on standby. Battery starts don't rely on the starting of cranky ground units (especially in cold weather) and generally minimize reaction time.

Taxi time is primarily dependent upon the physical location of the alert parking area relative to the runway. The closer (and the more direct routing) the runway --- the lower the taxi time.

Flyout time is directly proportional to basic aircraft performance capability, i.e. available thrust, weight, climb capability, etc. The more acceleration -- the faster the takeoff - the faster the climb - the lower the flyout time, particularly for the "one over the runway" threat. (Attacks where the enemy detonates several warheads in some optimized pattern are more difficult to analyze because safe escape is more difficult to define.) Aircraft performance is usually dictated by firm operational requirements such as maximum take-off distance, and range. These and other requirements allow little or no leeway for performance requirements to be driven by base escape. Normally, if the operational requirements are satisfied, the aircraft performance capability is more than adequate to provide acceptable P_{BE} --- if the other key base escape parameters have been optimized.

Generally base escape capability increases with dispersion, and with distance of the base from the sea coast (off which enemy submarines can launch missiles). However logistics support costs, possible command and control difficulty, and the sabotage potential also increase with dispersion. Another, less definable consideration in discussion of basing is the strategic value of a target to the enemy. If one base contains many alert aircraft, the strategic value may be sufficient for pattern attack, while a single aircraft base may only merit a single, "one over the runway" detonation.

Nuclear hardness for base escape basically refers to the capability of the aircraft to survive exposure to nuclear blast (gust and overpressure) and thermal environments*. This premise is based on the assumption that the enemy will maximize kill ranges by use of high-yield (several hundred kiloton to several megaton) weapons. For such weapons detonated at low altitude the dominant kill mechanisms are blast and thermal. Prompt nuclear radiation environments at ranges corresponding to aircraft kill for blast and thermal are inconsequential --- below inherent hardness levels of even <u>unhardened</u> systems.

* Electromagnet Pulse (EMP) hardness of the bombers is assumed for this exercise.

It is noted that crew reaction time, taxi time and basing are variables which can be varied throughout the operational life of the aircraft. If the international situation deteriorates, crews may be placed on cockpit alert, aircraft may be positioned at the end of the runway (with engines running for the worst case), and they may be dispersed as widely as necessary. Therefore a great deal of flexibility exists to increase the probability of base escape.

Now consider the remaining variables, aircraft reaction time, time to safe escape, and nuclear hardness. In general these characteristics are integral to the design of the aircraft, and if the need for increased survivability dictates, the aircraft design must be changed. Such retrofit design change usually is very expensive and time consuming.

A typical base escape analysis output is illustrated in figure 1. The ordinate is probability of base escape of the alert aircraft and the abscissa is the time from klaxon to safe escape. Detection of enemy launch and issuance of the command to launch the alert force are prerequisite actions. For simplicity it is assumed that the enemy has detonated a single nuclear warhead over the center of the runway and that his aim is perfect. If there are some number of alert aircraft at the base, then the probability of survival is simply the percentage that reach the safe escape point without experiencing nuclear blast and thermal environments greater than or equal to their hardness. Those aircraft which are subjected to levels greater than their hardness levels are assumed to be "killed", i.e. no longer capable of mission completion, although they may not be totally destroyed. (This simplistic approach illustrates the principle. Actual analyses would consider CEPs, pattern attacks as well as the "one-over-the-runway" attack, and numerous other factors.)

In figure 1, note that for very short base escape times, (region I) P_{BE} is very high and for very extended base escape times, (region III) P_{BE} is very low. Note that in these regions, nuclear hardness and/or basing are not critical factors. If the base escape times are ultra low, or very lengthy, then the alert aircraft will either survive or be killed, irrespective of their hardness.

The pay off for hardness can be seen in region II. Note that the curves fan out with hardness. Higher hardness levels result in higher P_{BE} for a given base escape time, or for a given P_{BE}, increased hardness results in longer allowable base escape times. A somewhat similiar graph can be generated for various basing schemes, and graphs combining basing and nuclear hardness also can be generated. In the combined curves, the nuclear hardness levels fan out from each basing plan.

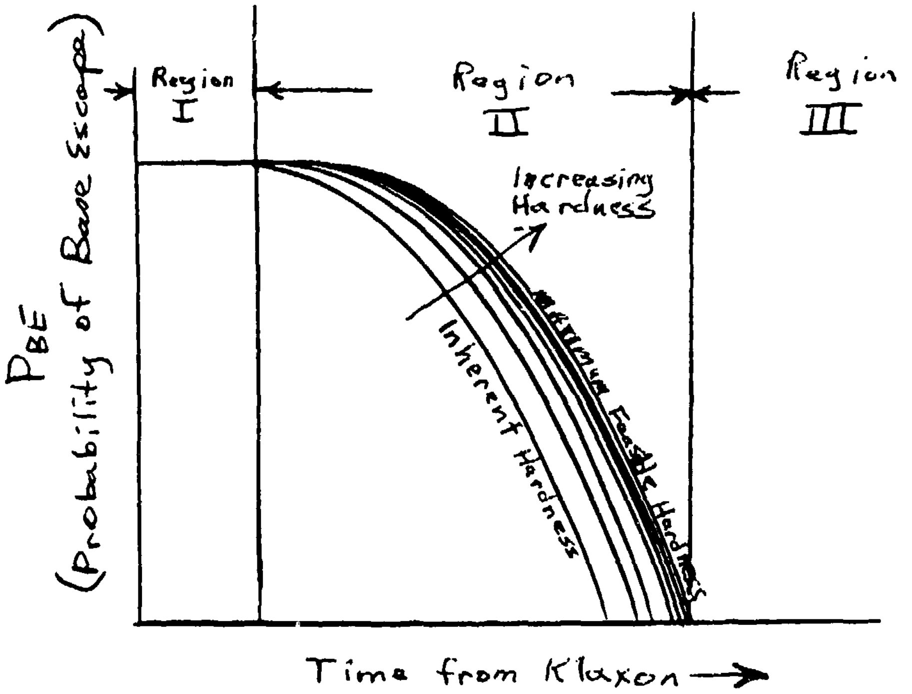

Figure 1. Representation of the Probability of Base Escape for a given Basing Plan.

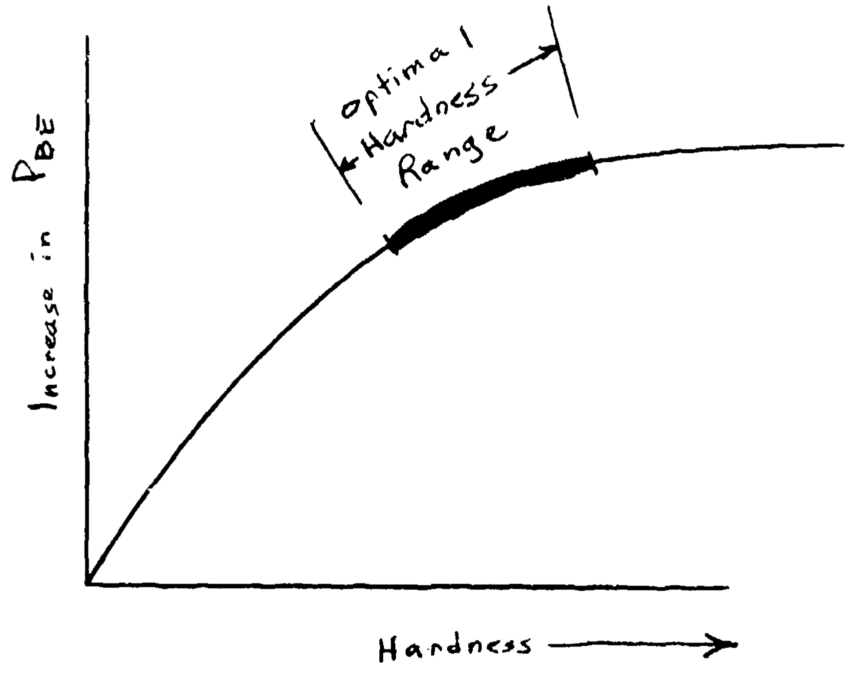

Figure. 2. Representation of Hardness Optimization.

It is noted that hardness and dispersal should complement each other for long-term, optimized base escape capability. They should not compete. Dependence upon dispersal alone to provide base escape capability may result in the need for more and more dispersion of a permanent nature to counter more severe future threats. The life cycle costs associated with large-scale, permanent disposal could greatly exceed the relatively small costs to design and maintain hardness. A more practical approach may be to harden the aircraft sufficiently to deter limited, counterforce attack, and use dispersal during periods of international tension to further enhance base escape cability.

The next area of interest is the selection of the optimal hardness levels. After studying figure 1, the approach appears to be obvious. Choose the probability of base escape required for credible deterence. That point defines a unique set of hardness levels and base escape times. Conduct trade off analyses to fix the optimal hardness level consistent with achievable base escape times, hardening technology, and the cost associated with each set of hardness-level and base-escape-time parameters.

However there are problems with this approach. First, the probability of base escape required is difficult to quantify -- (and if quantified by a particular individual at a given time, it probably will be changed before the ink is dry). Another approach is to evaluate the effect of increasing hardness on the probability of base escape. That evaluation could result in a graph that looks something like figure 2. Note that initial increases in hardness provides significant changes in P_{BE}. But there is a knee in the curve above which further increases in hardness results in increasingly smaller gains in P_{BE}. The optimum hardness level is on the knee of the curve. This hardness level must be investigated to insure it is technically achievable. The cost to harden and maintain should also be analyzed to insure that that particular level does not pose severe cost impacts. If it does, another lower hardness level (but still in the knee region) would be analyzed until acceptable cost is obtained.

The engine start time necessary for acceptable survivability should be analyzed very carefully during the conceptual phase of the system acquisition program. Worst case estimates of the enemy threat, potential basing limitations, nuclear hardness, performance, alert crew restrictions, and detection and warning capability should be made. If the sequential engine start technique is not acceptable, or is marginally acceptable, then simultaneous start capability should be incorporated into the initial design.

Potentially serious future consequences of having marginal engine start times and/or blast and thermal hardness levels are (1) severe restriction of alert crews minimizing crew response times and/or (2) severe basing restrictions. Such actions may be required to provide the fleet survivability required to pose a credible deterrent. The long-term recurring cost of such action in degraded crew morale, and in the necessity for permanent dispersion may more than offset the costs of designing in low aircraft response times and nuclear hardness.

In fact, the warning time from breakwater to klaxon is not fixed, rather it could vary with equipment reliability, weather conditions, interference (natural or deliberate), enemy use of "stealth" on the missile, human factors, and other considerations. Therefore it can be argued that the blast and thermal hardness levels be maximized and aircraft response time be minimized early in the acquisition program. This approach would force consideration of quick-starting, high capacity APUs with capability to simultaneously start all engines rapidly and reliably, and to blast and thermal hardening early in the acquisition program.

ALTITUDE DEPENDENCE

In the previous section, base escape was discussed using a single burst over the runway attack. For such a case, the aircraft altitude at the time of exposure was relatively low and the environments, which vary with altitude, are near their sea-level values. However, if pattern attacks are involved, or if the enemy gains the ability to detect and attack the bombers during cruise phases of the mission, the altitude dependency can not be ignored.

Both the blast (gust and overpressure) and thermal environments at a given distance from the detonation vary with altitude. At higher altitudes the thermal environment generally is more severe at a given distance because atmospheric absorption and scattering effects decrease with density, and density decreases with altitude. Although complex in substance (atmospheric transmittance is a function both of the atmosphere and the wave length) the calculations of the incident thermal fluence are straightforward and the aircraft thermal hardness level remains relatively constant with altitude.

Nuclear blast is another story. The blast wave generated by a nuclear detonation results in two significant effects, both of which must be addressed for balanced hardness. These two effects are overpressure and gust. Overpressure is simply the rise in static pressure resulting from passage of the blast wave. The gust environment, usually stated in feet/second at sea level, is related to the dynamic pressure, q, behind the moving shock by the equation, $q = 1/2\, \rho V^2$ where ρ is the density and V the velocity of the air behind the shock. Gust velocities (in feet/second) historically have been specified for convenience to aerodynamicists analyzing the effects of the gust environment on system aerodynamics, and structure to determine its probability of survival. The gust and overpressure environments are linked. For a unique circumstance, i.e. altitude, atmospheric conditions etc., a given overpressure corresponds to a specific gust velocity, (and dynamic pressure, temperature, etc.). They are simply the result of solving the equations governing the shock wave.

Although the gust and overpressure are interdependent, the responses of the system to each are not. For example, a system may be hardened to 2 psi overpressure (and to the corresponding gust velocity of 103 ft/sec) at sea level. Since the overpressure is simply that --- a pressure added to the ambient ---, it seems reasonable that the system should also be hard to 2 psi overpressure at altitude. For example, consider 30,000 feet. An unpressurized system should experience little or no difference and a pressurized system should response even less.

However, considering that the ambient pressure is now only 4.4 psi (instead of the 14.7 psi at sea level), the effect of using a 2 psi overpresure increases the shock strength which increases the gust velocity (from 103 ft/sec to 275), and the dynamic pressure (from .095 psi to .307).

The increased gust velocity (if incident from the top or side of the aircraft) could result in overstress on wings, and/or horizontal/vertical tails.

If we are concerned about nuclear encounters at altitude we must ensure that supportable criteria be developed to ensure system survival. A major factor is that the altitude criterion be compatible with the sea level criteria.

Study of the potential nuclear blast vulnerabilities of aeronatical system suggest that overpressure hardness change with altitude should be minimal and that gust hardness from the front and rear of the system is significantly greater than side and top orientations. The system is aeronautically streamlined to minimize drag and can survive substantial gust loading from front and rear.*

If we limit consideration to the critical top and side orientations, we can simplify the problem by replacing the control surface perpendicular to the gust by a flat plate. We then subject the flat plate to a perpendicular gust, and calculate the force acting on the flat plate. This force, F, is

$$F = C_D q S$$

where C_D is the drag coefficient, q is dynamic pressure, and S is the area of the flat plate.

If we analyze each of the factors we find that the drag coefficient varies little for all flight conditions, and that the area is constant. Therefore the variable of interest in evaluating altitude effects upon the force is the dynamic pressure, q. Holding q constant with altitude should fix the force (and bending moment) on the control surface from perpendicular gust loading.

During the course of this study, numerous approaches (in addition to the above) were considered, i.e. holding the overpressure constant, holding the gust velocity constant, holding the blast wave mach number constant, and holding the Reynolds number constant. The first two approaches had no firm foundation in fluid mechanics or in aerodynamics, but rather were more exploratory and served as exercises in developing the iterative techniques needed to solve the blast wave equations at various altitudes.

* In rare cases, gusts may trigger oscillation of active control systems --- but this can usually be corrected electronically.

The blast mach number is directly related to shock strength regardless of all other factors. The mach number is the similarity parameter* relative to the shock itself ... no aircraft properties are involved. If the blast wave itself were of most interest, then the mach number parameter would be a likely candidate.

Another potential candidate is Reynolds Number, Re

$$Re = \frac{UL}{\nu}$$

Where the L is a characteristic length, U a characteristic velocity and ν the kinematic viscosity. The Reynolds Number is simply the ratio of inertial to viscous forces acting on a submerged body. Further investigation revealed that the skin friction drag of a submerged body is a function of the Reynolds Number, where the characteristic length and velocity are the distance from the leading edge of the body and the free stream velocity respectively. If we were analyzing potential effects by gusts from the front or rear, Reynolds Number similarity** would be pertinent. For gusts from the top and sides, Reynolds Number similarity is not the appropriate consideration.

For completeness and for purposes of comparison a table was constructed which shows the different overpressure and gust levels with altitude for all the above approaches. In this table, only side and top gusts are considered, therefore the characteristic length and velocity used in the Reynolds Number are the aircraft size and gust velocity. Holding the Reynold Number constant results in the following

$$\frac{U_1 L_1}{\nu_1} = \frac{U_2 L_2}{\nu_2}$$

but $L_1 = L_2$, therefore

$$U_2 = U_1 \frac{\nu_2}{\nu_1}$$

This relationship was used to determine the gust velocity at the altitude of interest (subscript 2) relative to sea level condition (subscript 1).

* Recall that similarity parameters ae used to establish similarity in two different situations. If the <u>pertinent</u> similarity parameters are equal, there is similarity between the two situations.

** Note that this Reynolds number should probably be based upon the aircraft velocity plus/minus the gust velocity (depending on direction of gust) and the control surface chord length.

	Altitude (Feet)	O.P. = 2 psi		Gust = 103 ft/sec		q = .095		M = 1.0567			Re = Const		
		Gust (ft/Sec)	q (psi)	O.P. (psi)	q. (psi)	OP (psi)	Gust (ft/sec)	OP (psi)	Gust (ft/sec)	q (psi)	OP (psi)	Gust (ft/sec)	q (psi)
	0	103	.095	2	.095	2	103	2	103	.095	2	103	.095
TROPO-SPHERE	5000	120	.114	1.72	.084	1.83	110	1.66	101	.079	1.94	116	.107
	10000	141	.137	1.45	.072	1.66	118	1.38	99	.066	1.88	132	.121
	15000	166	.166	1.21	.062	1.51	127	1.13	97	.054	1.80	150	.135
	20000	196	.203	1.01	.053	1.36	137	.92	95	.044	1.75	172	.155
	25000	232	.249	.83	.044	1.22	149	.74	93	.035	1.68	198	.177
	30000	276	.307	.68	.037	1.10	162	.59	91	.028	1.62	229	.204
	35000	328	.381	.55	.030	.98	176	.47	89	.022	1.56	266	.237
STRATO-SPHERE	40000	399	.477	.43	.024	.87	196	.37	89	.018	1.61	334	.315
	45000	483	.591	.34	.019	.77	219	.29	89	.014	1.70	425	.436
	50000	580	.729	.27	.015	.69	243	.23	89	.011	1.83	541	.615
	55000	692	.892	.21	.012	.61	271	.18	89	.009	1.99	688	.881
	60000	819	1.082	.17	.009	.54	302	.14	89	.007	2.20	874	1.280

Table I. Variable change with altitude for the candidate approaches.

An overpressure of 2 psi and corresponding values of gust velocity (103 feet/second) and dynamic pressure (.095) for sea level standard were selected as baseline values. These values should fall somewhere near the knee of curves like figure 2. If different values are desired, a mini-computer program reported separately * can be used to accomplish the calculations.

* Patrick, R. P., "Nuclear Blast Program for Mini-Calculators" Eng. Study, S-111, SAC/LGME, Offutt Air Force Base, Nebraska, March 1981.

RECOMMENDATIONS

To maximize the probability of base escape for the entire operational life of the system it is recommended that:

1. Nuclear blast and thermal criteria equal to or greater than the optimal levels discussed above be established as firm design-to requirements not later than the start of the full scale development of any new bomber.

2. A maximum engine start time should be established consistent with the minimally acceptable probability of base escape for the most critical basing scheme, enemy threat system performance, alert parking, alert crew reaction time, and any other factors critical to base escape. Even if single-engine starting is judged acceptable --- it is strongly urged that growth capability for simultaneous engine start be incorporated in the design.

> The above recommendations may result in a degree of overdesign with an attendant cost penalty. However, balanced against the relatively small cost delta for possibly unneeded capability is an enormous cost delta if that capability is not incorporated but is necessary in future years. The extra capability would also act as a hedge against possibly otherwise catastrophic delays in the reaction time for detection of the SLBM launch and the transmission of the alert launch order.

3. Basic similarity consideration for gust induced forces on potentially susceptible aircraft flight surfaces indicate that altitude dependence of sea level nuclear blast requirements would be minimized by use of a "constant q" requirement*. This requirement then should be specified in lieu of sea level overpressure and gust requirements.

* The "constant q" requirement is compatible with the usual overpressure and gust requirements at sea level, but is also applicable fo any other altitude.

APPENDIX A

A MINICOMPUTER PROGRAM

to solve the

Blast Wave for (1) Constant

Blast Wave Mach Number

and (2) Constant Reynolds Number

with Altitude

I Subroutine A. Standard Atmosphere.

This subroutine computes the pressure, temperature and density at the altitude of interest using standard atmosphere equations. Note that Part 1 is pertinent for the troposphere ($h \leq 36,150$ feet) where the temperature decreases linearly with altitude. Part 2 is pertinent for the stratosphere ($36,150 < h \leq 82,000$ feet) where the temperature is constant. (This subroutine is identical to that used in a companion study*.)

II Subroutine B - Blast Wave Mach Number

This subroutine accepts the blast wave mach number as input, and outputs the overpressure, gust velocity and dynamic pressure corresponding to the given mach number and altitude.

PRESS B	Initializes Subroutine
ENTER BLAST WAVE MACH NUMBER	
PRESS R/S	Overpressure (psi) is displayed
PRESS R/S	Gust Velocity (ft/sec) is displayed
PRESS R/S	Dynamic Pressure (psi) behind blast wave is displayed

For a given altitude, a new Mach Number may be entered simply by repeating the above steps. For a new altitude, subroutine A must be exercised prior to initialization of subroutine B. (Register contents are the same as those in the footnote.)

* Patrick, R.P., "Nuclear Blast Program for Mini-Calculators", Engineering Study S-111, SAC/LGME, Offutt Air Force Base, Nebraska, March 1981.

III. Subroutine C. Reynolds Number

This subroutine accepts a sea level gust velocity as input, and calculates the gust velocity at altitude required to maintain a constant Reynolds Number. In this program, the Reynolds' Number is based on a characteristic length, (chord length, or other characteristic length assumed constant), the gust velocity, and the kinematic viscosity. Since the aircraft velocity is not included, gusts from the top, bottom, and sides of the aircraft are addressed. However, these are most critical to vulnerability considerations.

PRESS C	Initializes Subroutine
ENTER SEA LEVEL GUST VELOCITY	(if a ratio of gust velocities is desired, enter 1)
PRESS R/S	Gust Velocity (or ratio) is displayed in same units as those input.

Blast Mach No. & Reynolds Number with Altitude

Appendix B

PROGRAM LISTING

Part I ($h \leq 36000$)

ØØ1	*LBLA	21 11	Ø27	Y^x	31	Ø53	Ø	ØØ
ØØ2	RCL9	36 Ø9	Ø28	STO2	35 Ø2	Ø54	Ø	ØØ
ØØ3	CLRG	16-53	Ø29	RCLØ	36 ØØ	Ø55	2	Ø2
ØØ4	P⇄S	16-51	Ø3Ø	5	Ø5	Ø56	3	Ø3
ØØ5	CLRG	16-53	Ø31	.	-62	Ø57	7	Ø7
ØØ6	R/S	51	Ø32	2	Ø2	Ø58	8	Ø8
ØØ7	STO9	35 Ø9	Ø33	5	Ø5	Ø59	x	-35
ØØ8	6	Ø6	Ø34	6	Ø6	Ø6Ø	STO5	35 Ø5
ØØ9	.	-62	Ø35	1	Ø1	Ø61	RCL3	36 Ø3
Ø1Ø	8	Ø8	Ø36	Y^x	31	Ø62	$\sqrt{X}$	54
Ø11	7	Ø7	Ø37	STO1	35 Ø1	Ø63	4	Ø4
Ø12	5	Ø5	Ø38	RCLØ	36 ØØ	Ø64	9	Ø9
Ø13	EEX	-23	Ø39	5	Ø5	Ø65	x	-35
Ø14	6	Ø6	Ø4Ø	1	Ø1	Ø66	STO6	35 Ø6
Ø15	CHS	-22	Ø41	8	Ø8	Ø67	RCL3	36 Ø3
Ø16	x	-35	Ø42	x	-35	Ø68	STOC	35 13
Ø17	CHS	-22	Ø43	STO3	35 Ø3	Ø69	RCL4	36 Ø4
Ø18	1	Ø1	Ø44	RCL1	36 Ø1	Ø7Ø	STOA	35 11
Ø19	+	-55	Ø45	1	Ø1	Ø71	RCL9	36 Ø9
Ø2Ø	STOØ	35 ØØ	Ø46	4	Ø4	Ø72	P⇄S	16-51
Ø21	4	Ø4	Ø47	.	-62	Ø73	STO9	35 Ø9
Ø22	.	-62	Ø48	7	Ø7	Ø74	*LBLB	21 12
Ø23	2	Ø2	Ø49	x	-35	Ø75	R/S	51
Ø24	5	Ø5	Ø5Ø	STO4	35 Ø4	Ø76	x^2	53
Ø25	6	Ø6	Ø51	RCL2	36 Ø2	Ø77	STOD	35 14
Ø26	1	Ø1	Ø52	.	-62	Ø78	5	Ø5

Ø79	+	-55	1Ø8	2	Ø2	137	$\sqrt{X}$	54
Ø8Ø	STOØ	35 ØØ	1Ø9	.	-62	138	x	-35
Ø81	ROLD	36 14	11Ø	8	Ø8	139	STOØ	35 ØØ
Ø82	7	Ø7	111	x	-35	14Ø	RCL5	36 Ø5
Ø83	x	-35	112	.	-62	141	x	-35
Ø84	1	Ø1	113	4	Ø4	142	RCLØ	36 ØØ
Ø85	-	-45	114	-	-45	143	-	-45
Ø86	ROLO	36 ØØ	115	2	Ø2	144	CHS	-32
Ø87	XY	-41	116	.	-62	145	STO7	35 Ø7
Ø88	÷	-24	117	4	Ø4	146	ROLD	36 14
Ø89	STOE	35 15	118	÷	-24	147	$\sqrt{X}$	54
Ø9Ø	.	-62	119	STO2	35 Ø2	148	RCL4	36 Ø4
Ø91	2	Ø2	12Ø	RCL1	36 Ø1	149	÷	-24
Ø92	x	-35	121	÷	-24	15Ø	RCLE	36 15
Ø93	1	Ø1	122	STO3	35 Ø3	151	$\sqrt{X}$	54
Ø94	+	-55	123	1/X	52	152	-	-45
Ø95	STOØ	35 ØØ	124	STO5	35 Ø5	153	STO6	35 Ø6
Ø96	ROLD	36 14	125	RCLA	36 11	154	X^2	53
Ø97	.	-62	126	RCL2	36 Ø2	155	RCLA	36 11
Ø98	2	Ø2	127	x	-35	156	x	-35
Ø99	x	-35	128	RCLA	36 11	157	RCL2	36 Ø2
1ØØ	1	Ø1	129	-	-45	158	x	-35
1Ø1	+	-55	13Ø	STOB	35 12	159	.	-62
1Ø2	ROLO	36 ØØ	131	RCLC	36 13	16Ø	7	Ø7
1Ø3	÷	-24	132	$\sqrt{X}$	54	161	x	-35
1Ø4	STO1	35 Ø1	133	4	Ø4	162	STO8	35 Ø8
1Ø5	$\sqrt{X}$	54	134	9	Ø9	163	RCLB	36 12
1Ø6	STO4	35 Ø4	135	x	-35	164	R/S	51
1Ø7	RCLD	36 14	136	RCLD	36 14	165	RCL7	36 Ø7

166	R/S	51
167	RCL8	36 Ø8
168	*LBLC	21 13
169	R/S	51
17Ø	STO4	35 Ø4
171	RCLC	36 13
172	5	Ø5
173	1	Ø1
174	8	Ø8
175	÷	-24
176	1	Ø1
177	.	-62
178	5	Ø5
179	Y^x	31
18Ø	STOØ	35 ØØ
181	RCLC	36 13
182	1	Ø1
183	9	Ø9
184	8	Ø8
185	.	-62
186	7	Ø7
187	+	-55
188	7	Ø7
189	1	Ø1
19Ø	6	Ø6
191	.	-62
192	7	Ø7
193	XY	-41
194	÷	-24
195	RCLØ	36 ØØ
196	x	-35
197	P⇄S	16-51
198	RCL2	36 Ø2
199	P⇄S	16-51
2ØØ	÷	-24
2Ø1	STO5	35 Ø5
2Ø2	RCL4	36 Ø4
2Ø3	x	-35
2Ø4	R/S	51

Part II

$36{,}000 < h \leq 82{,}000$

ØØ1	*LBLA	21 11	Ø27	5	Ø5	Ø53	x	-35
ØØ2	RCL9	36 Ø9	Ø28	3	Ø3	Ø54	STO2	35 Ø2
ØØ3	CLRG	16-53	Ø29		-62	Ø55	.	-62
ØØ4	P⇄S	16-51	Ø3Ø	3	Ø3	Ø56	Ø	ØØ
ØØ5	CLRG	16-53	Ø31	÷	-24	Ø57	Ø	ØØ
ØØ6	R/S	51	Ø32	8	33	Ø58	2	Ø2
ØØ7	STO9	35 Ø9	Ø33	STO7	35 Ø7	Ø59	3	Ø3
ØØ8	3	Ø3	Ø34	.	-62	Ø6Ø	7	Ø7
ØØ9	6	Ø6	Ø35	2	Ø2	Ø61	7	Ø7
Ø1Ø	EEX	-23	Ø36	2	Ø2	Ø62	x	-35
Ø11	3	Ø3	Ø37	3	Ø3	Ø63	STO5	35 Ø5
Ø12	STO8	35 Ø8	Ø38	4	Ø4	Ø64	RCL3	36 Ø3
Ø13	X≤Y?	16-35	Ø39	x	-35	Ø65	STOC	35 13
Ø14	GSB9	23 Ø9	Ø4Ø	STO1	35 Ø1	Ø66	RCL4	36 Ø4
Ø15	Ø	ØØ	Ø41	1	Ø1	Ø67	STOA	35 11
Ø16	÷	-24	Ø42	4	Ø4	Ø68	RCL9	36 Ø9
Ø17	LBL9	21 Ø9	Ø43	.	-62	Ø69	P⇄S	16-51
Ø18	3	Ø3	Ø44	7	Ø7	Ø7Ø	STO9	35 Ø9
Ø19	9	Ø9	Ø45	x	-35	Ø71	LBLB	21 12
Ø2Ø	Ø	ØØ	Ø46	STO4	35 Ø4	Ø72	R/S	51
Ø21	STO3	35 Ø3	Ø47	RCL7	36 Ø7			
Ø22	RCL8	36 Ø8	Ø48	.	-62			
Ø23	RCL9	36 Ø9	Ø49	2	Ø2			
Ø24	-	-45	Ø5Ø	9	Ø9			
Ø25	RCL3	36 Ø3	Ø51	7	Ø7			
Ø26	÷	-24	Ø52	1	01			

*Remainder of program is the same as Part I.

DISTRIBUTION

2 - AFWL/NT, Kirtland AFB, NM 87117
2 - ASD/ENFTV, Wright-Patterson AFB, OH 45433
2 - ASD/YYEH, Wright-Patterson AFB, OH 45433
2 - SAC/XPFS, Offutt AFB, NE 68113
2 - SAC/XPH, Offutt AFB NE 68113
1 - USAFSAM/RZW, Brooks AFB, TX 78235
2 - HQ USAF/LEY, Washington, DC
2 - HQ USAF/RDQ, Washington, DC
1 - HQ TAC/DR, Langley AFB, VA
1 - HQ TAC/LG, Langley, AFB, VA
1 - HQ USAFE/GE, Ramstein AB, GE
1 - HQ USAFE/LG, Ramstein AB, GE
1 - HQ AFLC/LO, Wright-Patterson AFB, OH
1 - DNA, Washington, DC 20305
1 - Henry Diamond Lab.,
2800 Powder Mill Rd
Adelphi, MD 20783
1 - ESD/CC, Hanscom AFB, MA 01731